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APPLICATION FOR UNITED STATES PATENT

Inventor: Richard N. Codos, William W. Collan, Robert B. Comerford, Angelo Quattrociocchi, Milan Badovinac

Title: METHOD AND APPARATUS FOR INK JET PRINTING

SPECIFICATION

WOOD, HERRON & EVANS, L.L.P.
2700 Carew Tower
441 Vine Street
Cincinnati, Ohio 45202
(513) 241-2324 (voice)
(513) 241-6234 (facsimile)
Attorney Docket No.: **LPPT-16**

METHOD AND APPARATUS FOR INK JET PRINTING

This is a continuation-in-part of U.S. Application Serial No. 09/932,427, filed August 17, 2001, which is a continuation-in-part of U.S. Patent Application Serial No. 09/824,517, filed April 2, 2001, which is a continuation-in-part of U.S. Patent Application Serial No. 09/823,268, filed March 30, 2001.

This application is also a continuation-in-part of provisional U.S. Patent Applications Serial No. 60/327,622, filed October 5, 2001, and Serial No. 60/333,319, filed November 26, 2001, both hereby expressly incorporated by reference herein.

This application is also related to U.S. patent applications filed March 30, 2001 and entitled "Method and Apparatus for Printing on Rigid Panels and Other Contoured or Textured Surfaces", Serial No. 09/822,795 and "Printing and Quilting Method and Apparatus", Serial No. 09/822,794, each commonly owned with the present application and each hereby expressly incorporated herein by reference.

This application is also related to U.S. Patent Application Serial No. 09/390,571, filed September 3, 1999 and of International Application Serial No. PCT/US00/24226, filed September 1, 2000, of which U.S. Application Serial Nos. 09/932,427 , 09/824,517 and 09/823,268 are continuations in part, which are commonly owned with the present application and are each hereby expressly incorporated herein by reference.

Field of the Invention:

The present invention relates to ink jet printing, and particularly useful for ink jet printing onto textiles, onto wide web, large panel and other extended area substrates, and onto other substrates on a high speed and commercial scale.

Background of the Invention

Needs have arisen for the printing of large banners, flags and signs in quantities that are not economical for many conventional printing processes. Proposals have been made to print such products from electronic source files that can be processed directly on the printing press or printing system, rather than through steps such as film image-setting and plate-making. One such process is ink-jet printing. These processes have been attempted on surfaces such as vinyl, but printing with success onto textile surfaces has been even more limited. Such processes have been slow and lack reliability. The clogging of print heads in ink jet printing has been too frequent for use in wide width and large area substrates, and the processes used have not produced acceptable printing on textile materials.

The printing of substrates that are more than several feet, or a meter, wide, referred to as the special category of "wide width" printing, into which category the printing of signs and banners, office partitions , mattress ticking and most other quiltable materials would fall, is beyond many of the limitations of conventional printing methods. A number of technical problems exist that have deterred the development of the printing of

wide fabrics such as mattress covers, upholstery, automobile seat cover fabrics, office partitions and other wide width substrates.

Wide width products are frequently printed in relatively small quantities. Traditional printing typically involves the creation of a plate, a mat, a screen, or some other permanent or at least tangible, physical image from which ink is transferred to the object being printed. Such images contribute a relatively high set up cost that is only economical where the number of identical copies of the product is large. At the other extreme, office printers, for example, print a single copy or a small number of copies of a given document or other item, and are currently of the type that uses no permanent, physical image transfer element, but which rather prints from a software or program controlled electronic image, which can be changed from product to product. Such printing is sometimes referred to as direct digital printing, although the process need not necessarily be literally "digital" in the sense of a set of stored discrete numerical values. Ink jet printers are a common type of such direct digital printers in use today.

Ink jet printers print by projecting drops of ink on demand onto a substrate from one or more nozzles on one or more print heads. Office printers and other narrow width ink jet printers usually dispense water based or other solvent based inks onto the substrate by heating the ink and exploding bubbles of the ink out of the nozzles. These printers are often called bubble jet printers. The ink from such printers dries by evaporation of a solvent. Sometimes additional heat is used to evaporate the solvent and dry the ink. Printing onto wide width substrates with bubble type ink jet printers, or ink jet printers that use high temperature techniques to propel the ink, suffer from limited printhead life or high mean time between failures that require downtime and servicing. The heat used to expel the ink and to cause the evaporation of the solvents, evaporation that occurs during printhead downtime, and the thermal cycling of the heads, causes these print heads to clog or otherwise fail after as little as 20 milliliters of ink is dispensed. Office printers are, for example, often designed so that the print head is replaced every time a reservoir of ink is replenished. For this reason, for larger scale ink jet printing processes, such as wide width printing of films used for outdoor advertising, signage and architectural applications, print heads that use mechanical ink propulsion techniques are more common. Such mechanical print heads include piezo or piezo-crystal print heads, which convert electrical energy into intra-crystal vibrations that cause drops of ink to be ejected from print head nozzles.

Piezo print heads are particularly useful for applying inks that dry by polymerization which can be brought about after the ink leaves the print head and is deposited onto the substrate, usually by exposure to some form of energy medium such as electromagnetic or particle radiation. Inks have been formulated for ink jet printing that can be polymerized by exposure to a radiation curing source such as a focused beam of ultra violet light (UV) or high energy beams of electrons (EB). The inks generally incorporate stabilizers which prevent premature curing due to low levels of light exposure. Therefore, the inks usually require exposure to some threshold level of energy to initiate a polymerization reaction. Unless exposed to such threshold energy levels, such inks do not polymerize and remain stable, with a low tendency to dry in the nozzles or elsewhere unless cured by adequate exposure to the energy medium.

Solvent based inks are primarily cured by evaporation of the solvents. Some solvent based inks can be cured only by air drying, while others require the application of heat to enhance the evaporation of the solvent. In some cases, heat will facilitate a chemical change or polymerization of the ink along with an evaporation of a solvent. Polymerizable inks include monomers and oligomers that polymerize, and other

additives. UV curable inks polymerize when exposed to UV light at or above the threshold energy level. These UV curable ink formulations include photo-initiators which absorb light and thereby produce free radicals or cations which induce cross-linking between the unsaturation sites of the monomers, oligomers and polymers, as well as other additive components. Electron beam-cured inks do not require photo-inhibitors because the electrons are able to directly initiate cross-linking.

Heat or air curable inks that are organic solvent based or water based inks often do not have as high a color intensity as UV curable or other polymerizable inks because the pigments or dyes that produce the color are somewhat diluted by the solvent. Furthermore, organic solvents can produce an occupational hazard, requiring costly measures be taken to minimize contact of the evaporating solvents by workers and to minimize other risks such as the risks of fire. Solvent based inks, whether applied with heat or not, tend to dry out and eventually clog ink jet nozzles. In addition, solvent based inks set by forming a chemical bond with the substrate, and accordingly, their formulation is substrate material dependent. As a result, the selection of solvent based ink varies from fabric to fabric. Specific ink compositions are paired with specific fabric compositions to improve the fastness of the ink to the fabric, which results from chemical or electrostatic bonds formed between the ink and the fabric. Where the selected ink composition does not react or otherwise has an affinity with the surface of the particular fabric, the ink merely maintains a physical contact with the fabric surface and typically is easily removed by water, another solvent or abrasion. With UV and other radiant beam-curable inks such as electron beam-cured inks, the bonding between the ink and fabric is primarily mechanical and not limited to specific combinations of ink and fabric.

Polymerizable inks, particularly those cured upon exposure to a radiation or energy medium, are difficult to cure on three dimensional substrates such as the surface of a textile. While UV curable inks are capable of providing higher color intensity and do not present the hazards that many solvent based inks present and can avoid nozzle clogging, printing with UV curable ink onto textile fabric presents other problems that have not been solved in the prior art. To cure UV ink, for example, it must be possible to precisely focus a UV curing light onto the ink. UV ink, when jetted onto fabric, particularly onto highly textured fabric, is distributed at various depths over the texture of the fabric surface. Furthermore, the ink tends to soak into or wick into the fabric. As a result, the ink is present at various depths on the fabric, so that some of the ink at depths above or below the focal plane of the UV curing light evade the light needed to cause a total cure of the ink. In order to cure, UV ink must be exposed to UV light at an energy level above a curing threshold. However, increasing the intensity of the curing light beyond certain levels in order to enhance cure of the ink can burn, scorch or otherwise have destructive effects on the deposited ink or the fabric. Furthermore, ink jet printing can be carried out with different ink color dots applied in a side-by-side pattern or in a dot-on-dot (or drop-on-drop) pattern, with the dot-on-dot method being capable of producing a higher color density, but the higher density dot-on-dot pattern is even more difficult to cure when the cure is by UV light.

In addition, UV ink can be applied quickly to reduce wicking and UV ink can be developed to allow minimized wicking. Some wicking, however, can help to remove artifacts. Further, many inks developed to eliminate wicking leave a stiff paint-like layer on the surface of the fabric, giving the fabric a stiff feel or "bad hand". Therefore, to reduce the UV curing problem by eliminating wicking is not always desirable.

UV curing of jetted ink on fabric has been plagued by a limited cure depth that is determined by the depth of field of the focused curing UV light. When UV curable ink is jetted onto fabric, UV light may be

ineffective to cure a sufficient portion of the ink. A large uncured portion of the deposited ink can cause movement of the ink or the loss of the ink over time, resulting in deterioration of the printed images. Even if a sufficient portion of the ink is cured to avoid visibly detectable effects, uncured ink at some level has the possibility of producing symptoms in some persons who contact the printed fabric. The amount of uncured monomers or ink components that can cause problems by inhalation or direct skin contact has not been officially determined, but standards exist for determining limits for components of packaging material ingested with food. For example, if more than approximately 100 parts per million (PPM) of ink from packaging material is present in food, some persons who are sensitive to the uncured monomers may suffer reactions and others may develop sensitivities to the material. Such criteria assumes that 1 square inch of packaging material makes contact with ten grams of food. Thus, to interpret this criteria, it is assumed that each PPM of ink component in packaged food is equivalent to 15.5 milligrams of ink component migrating out of each square meter of packaging material into the food. While this does not provide an exact measure of the amount of uncured ink components that might be harmful to humans, it suggests that approximately 10% of uncured ink components on items of clothing, mattress covers or other fabrics with which persons may be in contact for extended periods of time, may be unacceptable.

For the reasons stated above, UV curable inks have not been successfully used to print onto fabric where a high degree of cure is required. Heat curable or other solvent based inks that dry by evaporation can be cured on fabric. As a result, the ink jet printing of solvent based inks and heat curable or air dryable solvent based ink has been the primary process used to print on fabric. Accordingly, the advantages of UV or other radiation curable ink jet printing have not been available for printing onto fabric.

UV inks, other polymerizable inks and other stable inks are typically those that reside on the surface of the substrate. The color components of the inks are in the form of pigments suspended in a polymer or other curable matrix. When the printed substrate is washed or exposed to weather or wear, the ink coating usually fades or otherwise degrades. Inks containing dyes, on the other hand, provide color fastness because the dye dissipates into and becomes chemically or mechanically bonded to the fibers of the substrate. Such dye-based inks are particularly useful in printing on polyester substrates, where sublimation dyes effectively bond to the polyester fibers. But because such inks employing dyes as the color component have traditionally required a solvent to suspend and carry the dye to the substrate, dye-based inks have resulted in "drop-spread", wicking of the ink, or blurring of the images that are being printed. As a result, the need to reduce this drop-spread with dye-based inks has necessitated the use of transfer processes rather than direct digital printing.

Furthermore, in the ink jet printing of textiles, specifically those made of porous materials or open weave fabrics, the jetted ink passes through holes in the substrate and deposits onto the substrate support. Traditionally, an absorbent blotter-like layer is placed under the substrate to collect the excess ink. The handling and disposal of the ink carrying layer is messy and inconvenient.

There exists a need in printing of patterns onto mattress ticking and mattress cover quilts, as well as onto other types of fabrics, for a process to bring about an effective cure of ink compositions containing UV curable inks and to render practical the printing with UV curable inks onto fabric for clog free ink-jet printing with stable inks that are completely curable, result in color fast images, with a minimum of drop spread. Additionally, a better way is needed for handling excess ink that passes through porous textiles in an ink-jet printing process.

Summary of the Invention

Objectives of the present invention include providing ink-jet printing with stable inks, providing for the complete curing of such inks, and providing for producing color fast images with such printing, particularly with a minimum of drop spread. A further and more particular objective of the invention is to provide for the ink jet printing of dye-based inks.

One objective of the present invention is to provide an effective method and apparatus for wide width direct digital printing, and for printing onto textiles. Another objective of the invention is to effectively apply a stable curable ink onto a textile or other substrate and to effectively cure the ink on the substrate with UV or other energy, a chemical curing agent or other curing medium, and particularly doing so using ink jet printing.

A further objective of the invention is to successfully apply and effectively cure ink jetted onto textiles and other substrates in a reliable manner without a tendency of the nozzles of the heads to frequently clog. Particularly, it is an objective of the invention to print onto textile fabrics and wide width substrates with a piezo or other mechanical or electro-mechanical print head.

Another objective of the invention is to provide for the printing onto textiles and other textured or wide width substrates using a printable substance that remains stable until deposited onto the surface of the substrate, and particularly by curing the substance a sufficiently short time from when the substance contacts the substrate to freeze the substance and prevent the spreading thereof. It is a further objective of the invention to do so while providing color fastness or other advantages of dye-based inks.

A particular objective is to provide such a process for printing with UV ink or other inks that are curable by exposure to impinging energy. A particular objective of the invention is to provide for the effective curing of UV inks jetted onto textile or fabric by reducing uncured monomers and other extractable non-solvent polymerization reactants, including reactant byproducts, or components of the ink, to a level most likely to be tolerable by or acceptable to persons contacting the printed substrates.

Another objective of the invention is to accommodate ink that is jetted through a porous or open weave substrate in a neat and efficient manner.

According to the principles of the present invention, a stable ink is digitally printed onto fabric and setting of the ink is initiated after the ink is deposited onto the substrate. By a "stable ink" is meant one that will not begin to cure, thicken or otherwise change properties in a way that will adversely affect the ability to apply the ink to the substrate, unless and until such ink is exposed to a curing medium that is otherwise absent from its environment. Inks that begin to set or which thicken upon evaporation of a solvent are not stable as herein defined. Inks that begin to polymerize before being exposed to UV light from a particular light source or to chemical agents that are provided to contact the inks after being applied to a substrate are also not considered stable.

In the preferred embodiment, stable UV ink monomers are deposited onto the substrate and polymerization of the ink is initiated by exposure to an impinged energy beam, such as UV, EB or other such energy beam. In accordance with certain aspects of the invention, the UV exposed or otherwise polymerization initiated ink is thereafter subjected to heat to reduce the content in the ink of unpolymerized polymerizable reactants and other extractable components of the ink to low levels that are likely to be tolerable or otherwise acceptable to persons contacting the fabric.

According to embodiments of the invention, stable dye components can are added to the otherwise polymerizable or stable ink or other printable colorant or substance to form a stable composition. The composition is digitally printed onto the substrate, whereupon the dye component is brought into contact with fiber surfaces in the fabric to chemically bond or form an affinity with those surfaces. Polymerization of the UV or other curable ink component is initiated by exposure to an impinged energy beam, such as UV, EB or other such energy beam. This exposure is preferably carried out upon contact of the substrate by the substance or immediately after. This effects at least a surface cure of the UV or other curable ink component, freezing the dots on the substrate surface and preventing dot spread, but generally has little effect on the dye component. Then the partially polymerized or cured printed substance is thereafter subjected to heat to complete chemical bonding of the dye or to finalize formation of its affinity to the fiber surfaces, and to reduce the unpolymerized polymerizable reactants and other extractable components of the UV or other curable component. In particular, the invention provides for an ink composition which contains, in combination with the UV ink or other inks curable by exposure to impinging energy, one or more dyes which are both reactive or have an affinity to some or all of the fiber surfaces of the fabric and are compatible with the UV or other curable ink. The UV inks or other inks curable by exposure to impinging energy are comprised of a polymerizable portion and at least one pigment, suspended in the polymerizable portion.

The ink composition incorporates a separate dye component which is combined with the UV or other impinging energy curable ink base. The base may or may not also contain pigment. The dye component of such ink compositions may be selected from the group including, but not limited to, dispersion dyes, reactive dyes, acid dyes, basic dyes, metallized dyes, naphthol dyes and dyes that do not require a post-treatment to either set the dye or to develop the color. Dispersion dyes are widely used for dyeing most manufactured fibers, including particularly the fibers of polyester and other synthetic textiles. Reactive dyes are anionic dyes which react with hydroxyl groups in cellulose fibers in the presence of alkali. Acid dyes are used on wool and other animal fibers, as well as certain manufactured fibers such as nylon. Basic dyes are positive-ion-carrying dyes which have a direct affinity for wool and silk. These dyes may also be used on basic-dyeable acrylics, modacrylics, nylons, and polyesters. Naphthol dyes are formed on the fiber by first treating the fiber with a phenolic compound in caustic solution and then applying a solution of a diazonium salt. the salt reacts with the phenolic compound to produce a colored azo compound. Generally, these dyes are used for cellulose fibers.

Dye based inks according to the present invention may also be applied to solid non-textile articles, as for example ceramic mugs and plates. Such articles are coated with acrylates or other polymeric substances to which dyes such as dispersion dyes can bond. With the invention, the traditional transfer printing process used for such articles can be replaced with direct digital printing with dye-based polymerizable ink.

In certain embodiments of the invention, a stable ink composition is jetted onto fabric and the set or cure of the ink is initiated by exposure to a chemical substance, energy or otherwise after it is ejected from the ink jet nozzles. In the preferred and illustrated embodiments, UV polymerizable ink is jetted onto the substrate where it is exposed to UV light for its cure. Preferably, a non-bubble jet print head such as a piezo-crystal or other mechanical ink ejection transducer is used to jet the ink. Heat may be applied to the piezo-crystal or other mechanical ink injection transducer during operation, but generally only to the extent necessary for ink viscosity reduction. With or following the exposure to the UV light, the printed fabric is subjected to heat, either in the form of a heated air stream, a heated platen or other heat source, which either extends the UV light initiated

curing process, drives off uncured components of the ink, or both. Any dye component suspended in the ink is also activated and set by the heat. With a sublimation dye component the suspended dye particles are believed to sublime into molecule sized particles which are highly reflective and produce intense color. These molecules disperse into cavities in the substrate, into pores on the textile fiber surface, or elsewhere in the cured matrix of the polymerizable ink component, where they are fixed upon cooling.

Typically one or more sets of four print heads are provided on a carriage, with each of the four heads of each set configured to scan the substrate sequentially to deposit each of four colors of a CMYK color set. In a preferred embodiment, two sets of four print heads each are configured so that each set prints the same four colors in a two printhead wide strip, or alternatively, the sets are configured and controlled to print over the same area with each of eight colors.

More particularly, UV curable ink is jetted onto the substrate, and the jetted ink is exposed to UV curing light to cure the UV ink component to an extent sufficient to render the printed image substantially resistant to further wicking, which is generally about 60 to 95% polymerization depending on ink density, substrate porosity and composition, and substrate weight and thickness. Preferably, UV light curing heads are mounted on the carriage carrying the printheads across the substrate, one on each side of the heads, with the lights alternating during the bidirectional motion of the printheads to expose the ink immediately after being deposited on the substrate with light from the trailing light curing head. The light curing heads are directed onto the substrate to expose the ink immediately after it contacts the substrate to freeze the dots of ink and curtain the wicking of the ink into textile and other absorbent fabric. Then, the fabric bearing the partially cured jetted ink is heated with heated air in a heat curing oven or by contacting the substrate with a heated platen or both, at which time the UV light initiated polymerization may continue, or uncured monomers are vaporized, or both, in order to produce a printed image of UV ink that contains a reduced level of uncured monomers or other components of the ink which is likely to be tolerable by persons sensitive or potentially sensitive to such ink components. Where dye is included in the ink, the presence of heat facilitates chemical bonding or affinity formation of unreacted dye in contact with fiber surfaces in the fabric. Preferably, the uncured components of the ink are reduced to an order of magnitude of about a gram per square meter, for example, and generally not more than about 1.555 grams per square meter of uncured monomer on the fabric substrate.

In the preferred embodiments, linear servo motors are provided to drive the print heads, at least transversely, over the substrate. Linear motors are easier to tune, require little service, and have better acceleration and deceleration than belt or other drive systems. Such servos provide accuracy that enables printing to be carried out while the heads are accelerating or decelerating. Programmed compensation is made for the variable head speed by the timing of the jetting of the ink. Thus, areas of the substrate having no printing can be skipped at high speed, greatly improving the speed and efficiency of the print operation by minimizing the time during which the print head is not depositing ink on the substrate.

To the extent that a dye component is included which does not bind chemically to the fiber surfaces or form an affinity, the portion of dye which does not react with the surfaces is encapsulated within the polymerized UV ink composition to minimize migration of the dye. This encapsulation effect reduces or eliminates the need for post-treatment to remove the mobile dye from the fabric.

According to the preferred embodiment of the invention, ink is jetted onto a textile material or a highly textured fabric such as a mattress cover ticking material, preferably prior to the quilting of the fabric into a

mattress cover. The ink is jetted at a dot density of about 180x256 dots per inch per color to about 300x300 dots per inch per color, though lower dot densities of from about 90x256 dots per inch or as low as about 90x90 dots per inch can be applied with acceptable resolution for certain applications. Typically, four colors of a CMYK color palette are applied, each in drops or dots of about 75 picoliters, or approximately 80 nanograms, per drop, utilizing a UV ink jet print head. A UV curing light head is provided, which moves either with the print head or independent of the print head and exposes the deposited drops of UV ink with a beam of about 300 watts per linear inch, applying about 1 joule per square centimeter. Generally, UV ink will begin to cure, at least on the surface, at low levels of energy in the range of about 20 or 30 millijoules per square centimeter. However, to effect curing in commercial operation, higher UV intensities in the range of about 1 joule per square centimeter are desired. Provided that some minimal threshold level of energy density is achieved, which can vary based on the formulation of the ink, the energy of the beam can be varied as a function of fabric speed relative to the light head and the sensitivity of the fabric to damage from the energy of the beam.

The fabric on which the jetted ink has been thereby partially UV cured is then passed through an oven where it is heated to about 300°F for from about 30 seconds up to about three minutes. Forced hot air may be used to apply the heat in the oven, but other heating methods such as infrared or other radiant heaters may be used. Alternatively, heated platens may be used to heat the ink bearing material, and such platens are particularly effective in bringing the material quickly up to the 300°F temperature. The UV energy level, oven heating temperature and oven heat time may be varied within a range of the above listed values depending on the nature of the fabric, the density, type and composition of the applied ink; and the speed of the fabric during processing relative to the UV curing light head. Thus, a higher ink density applied to the fabric will generally require more UV energy, higher oven heating temperature, longer oven heat time or a combination of these variables, to effect the necessary curing on the particular fabric. With dye-based inks, the temperature should be that most effective to set the dye, often over 350°F, for example, at about 385°F.

The reliability of the printing processes may be enhanced, according to certain aspects of the invention, by preconditioning the substrate, such as by precoating, shaving or singeing of the surface to be printed. Such preconditioning eliminates dust and lint that could collect on the print heads and potentially contribute to clogging of the nozzles.

The invention further provides an online printhead cleaning station for automatic cleaning of the printheads during the course of the printing process. Preferably, periodically during the course of the printing of an extended area substrate, the printhead carriage is traversed to the printhead cleaning station where ink is jetted from the heads to purge the nozzles and the heads are wiped of ink and foreign matter that might have collected on them.

The invention further provides for an ink composition which contains, in combination with the UV ink or other inks curable by exposure to impinging energy, one or more dyes which are both reactive or have an affinity to some or all of the fiber surfaces of the fabric and are compatible with the UV or other curable ink. The UV inks or other inks curable by exposure to impinging energy are comprised of a polymerizable portion and at least one pigment, suspended in the polymerizable portion.

Stable dye components can be added to the otherwise polymerizable ink to form a stable composition. The composition is digitally printed onto the substrate, whereupon the dye component is brought into contact with fiber surfaces in the fabric to chemically bond. Further, the amount of heat applied is that needed to cause

reaction or form an affinity with those surfaces. Polymerization of the UV or other curable ink component is initiated by exposure to an impinged energy beam, such as UV, EB or other such energy beam. This effects at least a surface cure of the UV or other curable ink component, but generally has little effect on the dye component. Then the partially polymerized or cured ink is thereafter subjected to heat to both complete chemical bonding of the dye or finalizing formation of an affinity to the fiber surfaces and reduce the unpolymerized polymerizable reactants and other extractable components of the UV or other curable ink component to low levels that are likely to be tolerable or otherwise acceptable to persons contacting the fabric. Where such dye is included in the ink, the presence of heat facilitates chemical bonding or affinity formation of unreacted dye in contact with fiber surfaces in the fabric.

Where the ink composition incorporates a separate surface of the substrate is a function of at least the dye component which is combined with the UV or other curable ink base, the dye portion of such ink compositions may be selected from dyes that are stable and are compatible with the ink and the substrate, and are selected from the group that includes, but is not limited to, disperse dyes, reactive dyes, acid dyes, basic dyes, metallized dyes, naphthol dyes and other dyes which do not require a post-treatment to either set the dye or to develop the color. Disperse dyes are widely used for dyeing most manufactured fibers. Reactive dyes are anionic dyes which react with hydroxyl groups in cellulose fibers in the presence of alkali. Acid dyes are used on wool and other animal fibers, as well as certain manufactured fibers such as nylon. Basic dyes are positive-ion-carrying dyes which have a direct affinity for wool and silk. these dyes may also be used on basic-dyeable acrylics, modacrylics, nylons, and polyesters. Naphthol dyes are formed on the fiber by first treating the fiber with a phenolic compound in caustic solution and then applying a solution of a diazonium salt. the salt reacts with the phenolic compound to produce a colored azo compound. Generally, these dyes are used for cellulose fibers.

To the extent that a dye component is included which does not bind chemically to the fiber surfaces or form an affinity, the portion of dye which does not react with the surfaces is encapsulated within the polymerized UV ink composition to minimize migration of the dye. This encapsulation effect reduces or eliminates the need for post-treatment to remove the mobile dye from the fabric.

Further, the amount of heat needed to cause reaction or form an affinity of the dye component, when included, with the fiber surface of the fabric is a function of at least the dye component concentration, dye chemical composition, fiber composition, and fabric processing speed past or through the heat source. Generally, the upper limits for the UV or other impinging beam of energy and oven heating temperature are those values which, when applied to the specific ink and fabric, begin to damage or otherwise adversely affect the applied ink, the underlying fabric or both.

The invention has the advantage that, for different inks and using different criteria for the desired residual amount of uncured ink components remaining on the substrate, the parameters can be varied to increase or reduce the residual amount. By increasing or decreasing the intensity of energy, or using a different form of energy than UV, or by increasing or decreasing the time of exposure of the ink to the energy, the amount of remaining unpolymerized non-solvent ink components can be changed. Additionally, using higher or lower temperatures, or more or less air flow, or greater or less heating time in the post curing oven, can change the final composition of the ink on the substrate. Care, however, should be taken that the energy curing or heating process does not damage the fabric or the ink.

A further advantage of the invention is that a portion of the ink composition can be included that will combine with fiber surfaces to provide coloration which is chemically bonded or has an affinity to those surfaces. Color or wash fastness due to chemical reaction or affinity formation of the dye to fiber surfaces over at least a portion of the printed fabric is accomplished while maintaining the advantage of mechanical bonding of the UV ink component onto other portions of the fiber.

The invention makes it possible to print images on fabric with UV curable ink by providing effective curing of the ink, leaving less than a nominal 1.5 grams of uncured monomers per square meter of printed material and usually leaving only about 0.15 grams per square meter of uncured monomers. Thus, the invention provides the benefits of using UV curable ink over water and solvent based inks, including the advantages of high color saturation potential, low potential sensitivity or toxicity, and without clogging the jet nozzles and enabling the use of piezo or other high longevity print heads. Furthermore, the encapsulation effect provided by the cured UV ink substantially or completely prevents migration of non-binding dye, if included, onto other sections of the fabric, or onto other fabrics as in the case of washing the printed fabric with other items. Furthermore, the ability to print on wide width fabrics with polymerizable inks, which do not form chemical bonds with the substrates, and therefore are not material dependent, provides an advantage, particularly with fabrics such as mattress covers and other furniture and bedding products.

The invention also makes possible the digital printing of sharp, clear images with dye-based inks on surfaces where the spreading of the dots has heretofore occurred.

In accordance with other principles of the invention, ink that passes through a porous or open weave substrate is collected and removed without contaminating the substrate. Where a substrate, for example, is a textile sheet or is in the form of a continuous roll-to-roll web that is fed through a printing station at, a carriage carries an ink jet printhead array across the substrate and jets ink onto the substrate. Where the substrate is porous or of an open weave, ink passes through the substrate. For such a substrate, a layer of protective film, preferably of the type to which the ink does not strongly adhere, underlies the substrate. A sheet of TEFLON or other non-stick material, may, for example, be used to cover a table on which the substrate is supported. Preferably, the substrate is maintained in tension or otherwise supported out of contact with an underlying surface, and a surface of a table in the region under the printhead is provided with the layer of protective film. Ink deposited onto the film may be partially cured, particularly where it is UV curable ink and UV light that is provided to cure ink on the substrate also partially impinges on the protective film. Where the substrate contacts the underlying surface, the film is preferably such that the adhesion between the jetted and partially cured ink and the layer of protective film is only great enough to prevent the ink from being wiped from its surface by the substrate. In any event, this adhesion is preferably such that ink can be easily removed by wiping or washing from the protective film layer.

The collection of Ink that is jetted from a printhead through a porous substrate is useful for all types of jetted ink, but particularly where the ink is UV curable ink. In such a case, a primary UV light curing source exposes the ink that has been jetted onto the substrate. Preferably, the curing light is mounted on or near the carriage to cure the ink immediately after it reaches the substrate so that the dots of ink are frozen before they have a chance to flow into the substrate or spread. As some ink passes through holes in the substrate and deposits onto the underlying release layer, UV light from the primary source exposes the ink on the layer may be directed to at least partially cure the ink deposited onto the protective film. In this case, the source preferably

emits essentially parallel UV light or light having a focal length sufficiently long that the light penetrates the substrate at the holes and cures ink on the underlying layer. Another UV curing source may alternatively be provided or provided in addition to the UV source on the primary source for curing ink on the release layer. The layer may be fixed so that the substrate moves parallel to it or may be in the form of a belt that moves with the substrate. The ink on the release layer, which is at least partially cured, may be wiped or vacuumed from the layer.

These and other objects of the present invention will be more readily apparent from the following detailed description of the preferred embodiments of the invention.

Brief Description of the Drawing

Fig. 1 is a diagrammatic perspective view of a one embodiment of a web-fed mattress cover printing and quilting machine embodying principles of the present invention.

Fig. 2 is a perspective view of an ink jet printing machine embodying principles of the present invention.

Fig. 3 is cross-sectional view of the printing machine of **Fig. 2**.

Fig. 4 is a perspective view of a portion of the machine of **Figs. 2** and **3**.

Fig. 5 is a top view of the portion of the machine illustrated in **Fig. 4**.

Fig. 5A is a perspective view of a portion of **Fig. 5**.

Figs. 6 and **6A-6D** are prints of display screens of the operator terminal and information bridge of the machine of **Fig. 1**.

Figs. 7A-7C are diagrams illustrating alternative embodiments of the feature of the invention by which ink jetted through a porous substrate is accommodated.

Detailed Description of the Preferred Embodiment

Fig. 1 illustrates a quilting machine 10 having a stationary frame 11 with a longitudinal extent represented by an arrow 12 and a transverse extent represented by an arrow 13. The machine 10 has a front end 14 into which is advanced a web 15 of ticking or facing material from a supply roll 16 rotatably mounted to the frame 11. A roll of backing material 17 and one or more rolls of filler material 18 are also supplied in web form on rolls also rotatably mounted to the frame 11. The webs are directed around a plurality of rollers (not shown) onto a conveyor or conveyor system 20, each at various points along the conveyor 20. The conveyor system 20 preferably includes a pair of opposed pin tentering belt sets 21 which extend through the machine 10 and onto which the outer layer 15 is fed at the front end 14 of the machine 10. The belt sets 21 retain the web 15 in a precisely known longitudinal position thereon as the belt sets 21 carry the web 15 through the longitudinal extent of the machine 10, preferably with an accuracy of 0 to 1/4 inch. The longitudinal movement of the belts 21 is controlled by a conveyor drive 22. The conveyor 20 may take alternative forms including, but not limited to, opposed cog belt side securements, longitudinally moveable positive side clamps that engage and tension the material of the web 15 or other securing structure for holding the facing material web 15 fixed relative to the conveyor 20.

Along the conveyor 20 are provided three stations, including an ink jet printing station 25, a UV light curing station 24, a heated drying station 26, a quilting station 27 and a panel cutting station 28. The backing material 17 and filler material 18 are brought into contact with the top layer 15 between the drying station 26 and the quilting station 27 to form a multi-layered material 29 for quilting at the quilting station 27. Preferably,

the layers 17,18 are not engaged by the belt sets 21 of the conveyor 20, but rather, are brought into contact with the bottom of the web 15 upstream of the quilting station 27 to extend beneath the web 15 through the quilting station 27 and between a pair of pinch rollers 44 at the downstream end of the quilting station 27. The rollers 44 operate in synchronism with the belt sets 21 and pull the webs 17,18 through the machine 10 with the web 15.

The printing station 25 includes one or more ink jet printing heads 30 that are transversely moveable across the frame 11 and may also be longitudinally moveable on the frame 11 under the power of a transverse drive 31 and an optional longitudinal drive 32. Alternatively, the head 30 may extend across the width of the web 15 and be configured to print an entire transverse line of points simultaneously onto the web 15.

The ink jet printing head 30 is configured to jet UV ink at 75 picoliters, or approximately 80 nanograms, per drop, and to do so for each of four colors according to a CMYK color pallette. Preferably, the printing head 30 does not undergo a heating step during operation. A mechanical or electro-mechanical print head such as a piezo print head is preferred. The dots are preferably dispensed at a resolution of about 180 dots per inch by about 256 dots per inch. The resolution may be higher or lower as desired, but the 180x256 resolution is preferred. If desirable for finer images or greater color saturation, 300x300 dots per inch is preferable. The drops of the different colors can be side-by-side or dot-on-dot. Dot-on-dot (sometimes referred to as drop-on-drop) produces higher density.

The print head 30 is provided with controls that allow for the selective operation of the head 30 to selectively print two-dimensional designs 34 of one or more colors onto the top layer web 15. The drive 22 for the conveyor 20, the drives 31,32 for the print head 30 and the operation of the print head 30 are program controlled to print patterns at known locations on the web 15 by a controller 35, which includes a memory 36 for storing programmed patterns, machine control programs and real time data regarding the nature and longitudinal and transverse location of printed designs on the web 15 and the relative longitudinal position of the web 15 in the machine 10.

The UV curing station 24 includes a UV light curing head 23 that may move with the print head 30 or, as is illustrated, move independently of the print head 30. The UV light curing head 23 is configured to sharply focus a narrow longitudinally extending beam of UV light onto the printed surface of the fabric. The head 23 is provided with a transverse drive 19 which is controlled to transversely scan the printed surface of the fabric to move the light beam across the fabric. Preferably, the head 23 is intelligently controlled by the controller 35 to selectively operate and quickly move across areas having no printing and to scan only the printed images with UV light at a rate sufficiently slow to UV cure the ink, thereby avoiding wasting time and UV energy scanning unprinted areas. If the head 23 is included in the printing station 25 and is coupled to move with the print head 30, UV curing light can be used in synchronism with the dispensing of the ink immediately following the dispensing of the ink.

The UV curing station 24, in the illustrated embodiment, is located immediately downstream of the printing station 25 so that the fabric, immediately following printing, is subjected to a UV light cure. In theory, one photon of UV light is required to cure one free radical of ink monomer so as to set the ink. In practice, one joule of UV light energy is supplied by the UV curing head 23 per square centimeter of printed surface area. This is achieved by sweeping a UV beam across the printed area of the fabric at a power of 300 watts per linear inch of beam width and exposing the surface for a time sufficient to deliver the energy at the desired density. Alternatively, if fabric thickness and opacity are not too high, curing light can be projected from both sides of

the fabric to enhance the curing of the UV ink. Using power much higher can result in the burning or even combustion of the fabric, so UV power has an upper practical limit.

The heat curing or drying station 26 is fixed to the frame 11, preferably immediately downstream of the UV light curing station. With sufficient UV cure to stabilize the ink such that the printed image is substantially resistant to further wicking, the ink will be sufficiently color-fast so as to permit the drying station to be off-line, or downstream of the quilting station 27. In embodiments in which a dye component is included in the ink composition, the dye will have either reacted or formed an affinity with certain fiber surfaces, or will have become substantially or completely encapsulated within the cured UV in component. When on-line, the drying station should extend sufficiently along the length of fabric to adequately cure the printed ink at the rate that the fabric is printed. Heat cure at the oven or drying station 26 maintains the temperature of the ink on the fabric at about 300°F for up to three minutes. Heating of from 30 seconds to 3 minutes is the anticipated acceptable range. Heating by forced hot air is preferred, although other heat sources, such as infrared heaters, can be used as long as they adequately penetrate the fabric to the depth of the ink.

The exact percentage of tolerable uncured monomers varies from ink to ink and product to product. Generally, it is thought that uncured monomers of UV curable ink should be reduced to below about 0.1%, or 1000 PPM. In the preferred embodiment of the invention, uncured monomers of UV curable ink are reduced to less than 100 PPM, and preferably to about 10 PPM. As explained above, each 1 PPM is equivalent to about 15.5 milligrams extractables per square meter of printed material. As used herein, the percentage or portion of remaining uncured monomers refers to the mass of extractable material that can be removed from a given sample of cured ink by immersing the cured ink sample in an aggressive solvent such as toluene, and measuring the amount of material in the solvent that is removed from the ink by the solvent. The measurements are made with a gas chromatograph with a mass detector. In the preferred embodiment of the invention, the measured amount of material removed from a given sample of the ink is less than 1.5 grams extractables per square meter of printed material. Measurements of higher than 100 PPM or 1.5 grams extractables per square meter of printed material are undesirable. Measurements of 10 PPM are preferred.

In certain embodiments, an ink composition comprising a UV ink component and a dye component are formulated in a manner which generates a compatible, shelf-stable composition. The relative concentration ranges of UV ink component to dye component in such compositions will vary with the nature of the fabric being printed, and the respective physical characteristics of the UV ink and dye components. Non-limiting physical characteristics of the UV ink and dye which are evaluated in connection with enhancing compatibility of the UV ink component with the dye component include polarity, viscosity, and pH. The dye and UV ink would be selected so that no reaction occurs or can be expected to occur between these ink components or with any other incorporated additive under the conditions expected during storage and printing operation.

The heating the dye-based cured ink may or may not be carried out to reduce the uncured level of uncured monomers of the curable component on the substrate. With the dye-based formulation, the heating step of the process causes the dye to set. With sublimation dyes, for example, heat causes dye particles to sublime into the substrate such as, for example, into polyester fabric fibers. The heating process causes dyeing by the dispersion process, particularly with a subclass of such dispersion dyes known as sublimation dyes, where heat causes the dye particles to change state from solid to gas directly. The heat opens pores in the polyester fiber allowing the gas to enter. It also is believed to cause the particles of dye to enter a molecular form which is more

highly reflective and capable of producing more brilliant color on the substrate. Once the material cools, the dye particles are trapped internally in the polyester fiber, possibly reverting back to their solid state or at least being fixed in the solid substrate fibers. Some of the dispersed dye may also be entrapped in pores in the matrix of the cured UV or other curable medium.

The matrix may be a polymerizable ink formulation or the clear polymerizable ink base with the dye suspended or otherwise contained therein. For example, the UV ink can be a clear UV ink or ink base that only contains dye particles. It may also, but need not contain an ink pigment. Effectively, using the clear base would result in all of the coloration being derived from the sublimation or other dispersion of the dye particles in the ink into the polyester fibers of the substrate, and from the potential dyeing of the clear UV polymer itself by the dye particles. This has several advantages over other ink jet dye processes. Firstly, spot curing with UV light freezes the UV ink drop immediately after in hits the substrate surface. Once this ink drop is heated, the dye sublimes at the exact point where it was frozen. This eliminates the "drop spread" associated with water based and other prior dye based ink jetting processes. With these other processes, the dye carrier, usually water, must be driven out from the substrate, or the dye must be heated to sublime, in order to limit the drop spread via wicking. This is extremely difficult to accomplish in a timely fashion relative to the point in time when the ink drop is jetted. Ultimately, controlling the drop spread results in clearer images with considerably higher levels of color saturation and "true" color gamut representation.

By using a clear UV base ink devoid of pigments, the resulting "hand" of the fabric is softer than ordinary UV based pigment ink systems. This is due to the fact that the coloration of the substrate, where a fabric of polyester or cotton/polyester mix, is accomplished via the sublimation of the dye particles. As a result, the fabric fibers are believed to be colored on a molecular level. With ordinary pigment systems, the pigment particle would remain in solid form, encapsulated within the UV matrix. Since these particles are very hard by nature, the result is a significantly stiffer fabric hand. The use of a UV clear base with only dye particles eliminates this hard hand.

The color retention after repeated washing of the clear UV + dye is extremely high. This is due to the fact that dyed fibers are the excellent at retaining their color fastness after repeated washings. The only effect the washings have upon the fabric is to wash away some level of the UV acrylate. Although a small percentage of the colored acrylate is lost during the wash process, the majority of dyed polyester fibers remain unaffected. At the same time, the hand of the material improves as the acrylate is washed away.

The use of UV based pigment inks that are also loaded with dye particles has several benefits. This type of ink system allows us to be unconcerned as to substrate composition. This is possible since the pigment based UV ink is substrate indifferent. At the same time, if the substrate contains a polyester or polymer, the dye portion of this ink will dye it during the heating/sublimation or other dispersion process. If the substrate is devoid of dyeable components, then the dye particles will color the UV polymer during the heating process. This combined dye + pigment matrix can afford the user the benefits of a substrate independent ink while offering the additional benefits of color fastness on washable materials containing polyester fibers or polymers. At the same time, this pigment + dye UV ink system retains all of the advantages discussed above.

With the dye-based inks, the heat sets the dye, which applies to many dyes and many substrates. UV ink can be only the ink base, without a pigment. Sublimation of dispersed dye is the mechanism applicable to polyester, but the concept is not limited to sublimation or to polyester. For polyester dyeing can occur by heating

the dispersed dye without getting to sublimation, but in practice, the majority of the dyeing involves sublimation. Sublimation was at one time thought to be something to be avoided. Dispersed dye can be used on polyester mix. It is thought that a UV ink matrix with reactive dye can be used for cotton. There are other dye groups. Most dye groups will work using a UV or other polymerizable matrix. Dyes that must be carried in solution are believed to work less effectively, as is the case with acid dyes, such as mordant dyes. Direct or substantive dyes are expected to work with this process more effectively. For reactive dyes and dyes that require water solution, water matrix UV can be used, and steam setting can be used to set such dyes.

In addition to heat, other mechanisms can be used for setting the dye, which can be determined from those mechanisms commonly used with particular dyes and substrate combinations. However, the major and most important commercial use expected in the near future will involve heat curing of UV carried dye on polyester.

Referring further to **Fig. 1**, the quilting station 27 is located downstream of the oven 26 in the preferred embodiment. Preferably, a single needle quilting station such as is described in U.S. Patent Application Serial No. 08/831,060 to Jeff Kaetterhenry, et al. and entitled Web-fed Chain-stitch Single-needle Mattress Cover Quilter with Needle Deflection Compensation, which is expressly incorporated by reference herein, now U.S. Patent No. 5,832,849. Other suitable single needle type quilting machines with which the present invention may be used are disclosed in U.S. Patent Applications Serial Nos. 08/497,727 and 08/687,225, both entitled Quilting Method and Apparatus, expressly incorporated by reference herein, now U.S. Patents Nos. 5,640,916 and 5,685,250, respectively. The quilting station 27 may also include a multi-needle quilting structure such as that disclosed in U.S. Patent No. 5,154,130, also expressly incorporated by reference herein. In the figure, a single needle quilting head 38 is illustrated which is transversely moveable on a carriage 39 which is longitudinally moveable on the frame 11 so that the head 38 can stitch 360° patterns on the multi-layered material 29.

The controller 35 controls the relative position of the head 38 relative to the multi-layered material 29, which is maintained at a precisely known position by the operation of the drive 22 and conveyor 20 by the controller 35 and through the storage of positioning information in the memory 36 of the controller 35. In the quilting station 27, the quilting head 38 quilts a stitched pattern in registration with the printed pattern 34 to produce a combined or composite printed and quilted pattern 40 on the multi-layered web 29. This may be achieved, as in the illustrated embodiment by holding the assembled web 29 stationary in the quilting station 27 while the head 38 moves, on the frame 11, both transversely under the power of a transverse linear servo drive 41, and longitudinally under the power of a longitudinal servo drive 42, to stitch the 360° pattern by driving the servos 41,42 in relation to the known position of the pattern 34 by the controller 35 based on information in its memory 36. Alternatively, the needles of a single or multi-needle quilting head may be moved relative to the web 29 by moving the quilting head 38 only transversely relative to the frame 11 while moving the web 29 longitudinally relative to the quilting station 27, under the power of conveyor drive 22, which can be made to reversibly operate the conveyor 20 under the control of the controller 35.

In certain applications, the order of the printing and quilting stations 25,27, respectively, can be reversed, with the printing station 25 located downstream of the quilting station 27, for example the station 50 as illustrated by phantom lines in the figure. When at the station 50, the printing is registered with the quilting previously applied at the quilting station 27. In such an arrangement, the function of the curing station 26 would

also be relocated to a point downstream of both the quilting station 27 and printing station 50 or be included in the printing station 50, as illustrated.

The cutoff station 28 is located downstream of the downstream end of the conveyor 20. The cutoff station 28 is also controlled by the controller 35 in synchronism with the quilting station 27 and the conveyor 20, and it may be controlled in a manner that will compensate for shrinkage of the multi-layered material web 29 during quilting at the quilting station 27, or in such other manner as described and illustrated in U.S. Patent No. 5,544,599 entitled Program Controlled Quilter and Panel Cutter System with Automatic Shrinkage Compensation, hereby expressly incorporated by reference herein. Information regarding the shrinkage of the fabric during quilting, which is due to the gathering of material that results when thick, filled multi-layer material is quilted, can be taken into account by the controller 35 when quilting in registration with the printed pattern 34. The panel cutter 28 separates individual printed and quilted panels 45 from the web 38, each bearing a composite printed and quilted pattern 40. The cut panels 45 are removed from the output end of the machine by an outfeed conveyor 46, which also operates under the control of the controller 35.

Piezo print heads useful for this process are made by Spectra of New Hampshire. UV curing heads useful for this process are made by Fusion UV Systems, Inc., Gaithersburg, Maryland.

An alternative embodiment of the invention is the ink jet printing machine 600 illustrated in **Fig. 2**. The machine 600 is a roll-to-roll ink jet printing machine that is particularly configured for printing onto wide textile webs. Such machines are particularly useful for printing a facing layer of material which may then be transferred to a quilting machine on a separate quilting line or to feed material downstream to a quilting station as in the embodiment illustrated in **Fig. 1**, described above. The machine 600 is also particularly suited to print on textiles that are not necessarily to be used in a quilted product, such as for signs, banners, apparel and other products.

The printing machine 600 has a stationary housing 601 with a longitudinal extent represented by arrow 602 and a transverse extent represented by arrow 603. The machine 600 has a front end 604 from which is advanced a substrate web of textile material 605 downstream in the longitudinal direction. The material may be a greige goods textile material or some other material on which printing is desired. Where the material is a textile, it can have been preconditioned by precoating, shaving or singeing of the surface to be printed to eliminate dust and lint that could collect on the print heads and potentially contribute to clogging of the nozzles. Failure to remove the fuzz can cause the fuzz or dust to be sucked into the nozzle orifices as the flow reverses between dot ejections, which could clog the nozzles.

An operator station 606 is provided at the right side of the front end of the housing 601 having a push button control panel 607 and a touch screen and display 608. The housing 601 includes a base assembly 609 which supports the machine 600 and encloses the supply of substrate material as described in connection with **Fig. 3** below. Across the top of the housing 601 transversely and supported on the base 609 extends an information bridge 610. The information bridge 610 has four display screens 611-614 facing the front 604 of the machine 600. From the control panel 606 an operator can select the information to be displayed on each of the screens 611-614. Such information can include status data, machine parameter settings, scheduling, batch and product information, pattern data, machine status and alarm conditions, or other information useful in operating the machine. One or more of the screens 611-614 can also be set to display video images of the

printing area or the substrate downstream of the printing station from information captured by video cameras (not shown) mounted on the machine 600.

The base 609 of the housing 601 has a conveyor table 615 on the top thereof on the upwardly facing horizontal surface of which is supported a length of the substrate web 605 for printing, as illustrated in **Figs. 3** and **4**. The conveyor table 615 has a conveyor belt 616 that extends transversely across the width of the table 615 on transversely extending rollers 617 and 618 that are respectively rotatably mounted at the front and back of the base 609 of the housing 601. The belt 616 extends across the width of the frame 601 and rests on a smooth stainless steel vacuum table 620, which has therein an array of upwardly facing vacuum holes 621 which communicate with the underside of the belt 616. The belt 616 has a high friction rubber-like polymeric surface 622 to help prevent a horizontal sliding of the substrate 605 and through which an array of holes 623 is provided to facilitate communication of the vacuum from the vacuum table 620 to the substrate 605. The belt 616 is inelastic and has an open weave backing 107 which provides dimensional stability to the belt 616 while allowing the vacuum to be communicated between the holes 621 of the vacuum table 620 and the holes 623 in the surface 622 of the belt 616. The forward motion of the substrate 605 relative to the on the housing 601 is precisely controllable by indexing of the belt 616 by control of a DC brushless servo drive motor 624 (**Fig. 3**) for the rollers 617,618 with signals from a controller 625 behind the operator panel 606 on the housing 601. The indexing of the belt 616 is controllable to an accuracy of about 0.0005 inches to move the substrate web 605 relative to the housing 601.

Fixed to the base 609 of the housing 601 and extending transversely thereof is a printing bridge 630, above the conveyor table 615 and below the information bridge 610. The printing bridge 630 supports a print head carriage 631 for transverse movement above and parallel to the substrate 605 supported on the conveyor table 615, as illustrated in more detail in **Figs. 3** and **4**. The bridge 630 has a pair of rails 632 on the front side thereof on which the carriage 631 is adapted to move. A linear servo motor 633 has a stator bar 633a containing a linear array of permanent magnets mounted across the front face of the printing bridge 630 and an armature 633b fixed to the carriage 631 and electrically connected through a wire cage chain 634 on the bridge 630 to the controller 625. An encoder 636 also extends across the front of the bridge 630 and provides feedback information to the controller 625 as to the position of the carriage 631 on the bridge 630. Linear motors such as the servo motor 633 are preferred because they are easier to tune, require little service, and have better acceleration and deceleration than belt or other drive systems. Because of their accuracy, printing can be carried out while the heads 640,641 are accelerating or decelerating, with programmed compensation in the timing of the jetting of the ink being made by the controller 625. This improves the speed and efficiency of the print operation by allowing the print heads 640,641 to use acceleration and deceleration time and to skip at high speed across areas of the substrate 605 that will have no printing and to areas at which ink is to be deposited, thereby minimizing the time during which the print head is not depositing ink on the substrate. Accordingly, linear servo motors to transversely move the carriage 631 that carries the print heads 640,641across the bridge 630 are preferred for the machine 600.

The print head carriage 631 has fixed at the bottom thereof two sets 640,641, each having four ink jet print heads 640a-d,641a-d. The print heads of each set are arranged in a transverse row so that they print successively along a transverse strip across the substrate 605 as the print head carriage 631 moves transversely across the bridge 630 to respectively apply the four colors of a CMYK color set. The ink jet printing heads

640a-d,641a-d each include a linear array of two hundred fifty-six (256) ink jet nozzles that extend in the longitudinal direction relative to the frame 601 and in a line perpendicular to the direction of travel of the carriage 631 on the bridge 630. The nozzles of each of the heads 640,641 are configured and controlled to simultaneously but selectively jet UV ink of one of the CMYK colors, and can print a strip of 256 pixels side by side across the substrate 605 at 15,000 dots per second. The spacing of the nozzles is, in the embodiment herein described, 90 jets per linear inch, so that the print heads are each slightly less than three inches wide. One pass of the print heads prints, for example, prints a transverse strip about 2.85 inches wide of ninety rows of pixels. With the two sets of heads 640 and 641, the strip is about 5.7 inches wide. By indexing the web 1/180th of an inch and printing with another pass of the carriage 631, which can be in the opposite direction, a longitudinal resolution of 180 dots per inch (dpi) can be achieved, as illustrated in **Fig. 5**. With four passes of the print heads, indexing between the scans 1/360th inch, a longitudinal dot resolution of 360 dpi can be achieved. Schemes to reduce artifacts and achieve different levels of printing quality involve activating half or one-third of the jets and scanning two or three times, indexing as required. Transverse resolution is settable at any resolution up to approximately 720 dpi by controlling the resolution and timing of the information sent by the controller 625 to the print heads. A transverse dot resolution is preferably maintained close to the longitudinal resolution being used.

Ink is supplied to each of the print heads 640a-d,641a-d by a respective one of a set of eight ink supplies (not shown) in the left side of the base 609 of the housing 601, which are connected to the respective heads through tubes carried by the wire cage 634. Each of the ink supplies includes a collapsible plastic bag and a peristaltic pump to supply UV ink to one of the ink jet print heads 640a-d,641a-d. Each collapsible supply bag is coupled to one of the peristaltic pumps via a tube that may include a quick disconnect. The peristaltic pump in turn supplies ink through a tube to a respective one of the ink jet print heads. An optional intervening reservoir may be provided in each tube between the pump and the print head to allow intermittent operation of the peristaltic pump or to handle intermittent demands exceeding pump output.

In the preferred and illustrated embodiment, the ink is ultraviolet light polymerizable ink composed essentially of polymerizable monomers which are stable unless and until exposed to a sufficient level of UV light to initiate a polymerizing reaction. UV light is provided by a pair of UV curing heads 645,646 mounted on each side of the carriage 631 to expose the ink immediately after it is deposited onto the substrate 605 by the print heads 640,641. The UV light heads 645,646 operate alternatively, with the head on the side of the carriage that trails the print heads 640,641 being activated to freeze the dots of ink within approximately 0.05 to 0.20 seconds after being deposited as the carriage 631 moves transversely on the bridge at approximately forty inches per second. The location of the heads 645,646 has the advantage of curing any atomized UV ink that might be produced by the nozzles of the print heads, thereby turning the liquid monomers into a dust that is less likely to be harmful. An optional additional UV light curing head 647 may be provided on a separate carriage 648 (as shown in phantom in **Fig. 3**) to move across the back of the bridge 630 independently of the movement of the print head carriage 631 to more thoroughly cure the ink by scanning the substrate 605 downstream of the print heads 640,641.

The supply of the substrate material 605 is loaded on a roll 650 onto a sliding carrier 651 that slides out of the base 609 of the housing 601 for loading and returns to the position shown in **Fig. 3** for operation of the machine 600. The web of the material 605 extends from the roll 650 around an idler roller 652, around the

bottom of a vertically moveable accumulator roller 653 and over the conveyor belt 616 on the top of the conveyor table 615. The accumulator roller 653 is weighted and supported by the web of material 605 so as to apply a uniform tension on the web of material 605. The ends of the shaft of the roller 653 ride in vertical tracks configured to keep the roller level. Limit switches or other detectors (not shown) sense upper and lower positions of the accumulator roller 653 so that the amount of material advancing from the supply roll 650 can be controlled. At the rear or downstream end of the conveyor table 615, a pinch roller 619 is provided to clamp the web 605 against the belt 616 as it passes around the roller 618.

Below the nip of rollers 618 and 619 is provided a heater 660. The web of material 605 enters the heater 660, which heats the substrate 605 to reduce the content of uncured monomers of the UV ink in the same manner as the heating station 26 described above in connection with the embodiment 10 of **Fig. 1**. Rather than using heated air, as in the case of heating station 26, the heater 660 contacts the substrate 605 with one or more heated platens, which quickly bring the substrate to a temperature of 360°F within approximately one to two seconds. The heating station or heater 660 has a path therethrough of from about thirty inches to about forty inches for the web 605. The heater 660 includes an initial heated stainless steel bullnose platen 661 is positioned to contact the under surface of the material 605 opposite the side on which the ink from the print heads 640,641 has been deposited. The bullnose platen 661 brings the substrate 605 to a desired temperature of 300-380° in one to two seconds, where hot air takes from 30 seconds to 3 minutes. The web 605 passes over a second bullnose platen 662 downstream of the first platen 661, which contacts the ink bearing side of the substrate 605, insuring that the temperature of the substrate 605, and particularly the ink, is at the desired temperature throughout the thickness of the material 605. Once brought to temperature, the substrate 605 is maintained at the desired temperature by a series of additional plates 663,664. In lieu of the additional plates, other ways of maintaining the desired temperature for another thirty seconds more or less, such as with heated air or radiant heaters, would be adequate. An exhaust system (not shown) connects to the heater 660 to exhaust and dispose of any vapors that may contain monomers of the ink. Such exhaust may be connected to an electrostatic carbon filter and the air therefrom returned to the environment.

At the outlet of the heater 660 a series of rollers 666 take up and roll the printed material web 605. The series of rollers 666 includes another accumulator roller 667 which maintains tension on the web 605 downstream of the nip of the rollers 618,619.

As illustrated in **Fig. 5**, at the right side of the path of the print head carriage 631 is provided a head cleaning station 670. Periodically in the course of the printing of a web of material 605, for example, after the printing of some length of web, twenty meters for example, or whenever an operator determines that the heads need to be cleaned, the carriage 631 is traversed to the right side of the bridge 630 over the cleaning station 670. The cleaning station 670 is provided with a pan 671 for collecting ink. When the heads are moved to the cleaning station 670, they pass over a slot 672 in a wiper blade mounting block 673 and ink is jetted from the heads into the pan 671 to clear the heads. The cleaning station 670 is also provided with an array of longitudinally extending upwardly projecting polyurethane wiper blades 675 that are mounted to the block 673. The carriage 631 is operated to move on the bridge 630 to wipe the heads 640,641 back and forth over the wiper blades 675 to wipe the bottom faces thereof which house the nozzles free of excess ink or dust. The blades are made of a polymeric material such as polyurethane and held to the block 673 in slotted blade holder members 677 fixed to the top of the block 673. Slots 676 are provided in the block 673 so that ink wiped from the heads

by the blades 675 drains into the collecting pan 671. Once the heads are cleaned, the carriage resumes the scanning and printing of the web 605. Such head cleaning is programmed to occur automatically, periodically during the printing process, when an automatic head cleaning option is selected by the operator.

Operation of the machine 600 is carried out at the control panel 606 described above. **Fig. 6** illustrates the main control window 680 displayed on the screen 608 of the panel 606. The window 680 includes a function key 681 and set of buttons 682 for assigning functions to the hard buttons 607 on the panel 606, such as manually advancing the web 605, moving the slide 651 to load a roll 650 and facilitating other such operator procedures, and for selecting the information to be displayed on the screens 611-614 on the information bridge 610. The operator can manually choose a selected pattern, which is displayed in window 683, by pressing the button 684, to open the pattern select window 684a, which displays icons 683a of the available patterns, as illustrated in **Fig. 6A**. The operator can also set up printer parameters by pressing the button 685 on window 680, which opens the printer setup window 685a illustrated in **Fig. 6B**. The operator can further configure the printer by pressing the button 686 on window 680, which opens the printer configuration window, various pages 686a,686b of which are illustrated in **Figs. 6C** and **6D**. Input, printed output and other communication functions can be controlled by pressing the button 687 while diagnostic information can be displayed by pressing the button 688. Speed and timing information is displayed in boxes 689 while batch and job status data, such as items and quantities completed and job (product or customer) identification data is displayed in boxes 690. The machine 600 is configured to function in accordance with the batch control and automatic scheduling processes described in U.S. Patent No. 6,105,520, by James T. Frazer, Von Hall, Jr. and M. Burl White entitled Quilt Making Automatic Scheduling System and Method, hereby expressly incorporated by reference herein.

Fig. 7A shows a printing apparatus 700 through which a web or other substrate 711 of woven or knitted polyester textile material is being fed for printing. The apparatus 700 includes a support table 702 over which the web 711 is fed. A fixed bridge 713 extends transversely across the path of the web 711 over the table 702. A printhead carriage 714 is mounted to move across the bridge 713, driven by linear servo motors 717. On the carriage 714, an ink jet printhead 715 is supported and oriented so as to jet UV curable ink onto the substrate 711 on the table 702. Also mounted on the carriage 714 on opposite sides of the printhead 715 is a pair of UV light curing heads 716 oriented to expose UV ink jetted onto the substrate 711 immediately after the ink reaches the substrate.

The table 702 is made of metal, for example stainless steel, and has an upwardly facing surface that is coated, at least in the area on which the printhead 715 prints, with a layer of release material 704 such as TEFLON, a silicone release material or some other material to which the ink will either not stick, or will stick with such low adhesive force that it can be easily wiped or otherwise removed from the release material layer 704. Ideally, the release material layer 704 has enough adhesion to the ink to prevent it from wiping off by the passage of the substrate 711 over the table 702, but has sufficiently low adhesion to allow the ink to later be wiped or otherwise removed from the layer 704 with relative ease. Alternatively, the ink on the layer 704 may normally stick to the layer 704 but be removable with a solvent or other cleaning agent.

The UV curing heads 16 preferably have light sources that focus over a sufficiently long depth of field so as to expose and cure not only ink that deposits on the substrate 711 but that which passes through pores or holes in the weave of the substrate 711 and collects on the underlying release material layer 704. As a result, the ink on the release material 704 is sufficiently set or cured so as to be in a powder or otherwise substantially

solid state as it enters the cleaning station, so that it can be wiped or otherwise easily removed from the surface of the release material 704.

The table 702 may be a vacuum table, with vacuum holes 721 through the layer 704 to allow the vacuum to pass through to help hold the substrate 711 in place for printing.

Fig. 7B shows a printing apparatus 710 through which web 711 of woven or knitted polyester textile material is being fed for printing. The apparatus 710 includes a support table 712 over which the web 711 is fed. Fixed bridge 13 extends transversely across the path of the web 711 over the table 712. Printhead carriage 714 is mounted to move across the bridge 713, driven by linear servo motors 717. On the carriage 714, ink jet printhead 715 is supported and oriented so as to jet UV curable ink onto the substrate 711 on the table 712. Also mounted on the carriage 714 on opposite sides of the printhead 715 are UV light curing heads 716 oriented to expose UV ink jetted onto the substrate 711 immediately after the ink reaches the substrate.

Positioned over the table 712 between the table 712 and the substrate 711 is a sheet of release material 720, such as TEFLON or a silicone coated film material or some other material to which the ink will not easily stick or will stick with such low adhesive force that it can be easily wiped or otherwise removed from the surface of the release material 720. The release material 720, in the apparatus 710, is in the form of a web or endless belt. The belt of release material 720 moves with the substrate 711 through the apparatus 710 and returns through a path 722 under the table 712. Along the path 722 is a cleaning station 723 through which the belt of release material 720 passes. The cleaning station 723 contains brush and vacuum elements (not shown) which wipe ink from the surface of the belt 721 and remove it to a filter (not shown).

The UV curing heads 716 preferably have light sources that focus over a sufficiently long depth of field so as to expose and cure not only ink that deposits on the substrate 711 but that which passes through pores or holes in the weave of the substrate 711 and collects on the underlying belt of release material 720. As a result, the ink on the release material 720 is sufficiently set or cured so as to be in a powder or otherwise substantially solid state as it enters the cleaning station, so that it can be wiped or otherwise easily removed from the surface of the release material 720.

Where the substrate is sufficiently porous for the ink to pass through it, but not sufficiently porous to allow enough UV light to pass so as to cure the ink on the protective material, the moveable belt may be used to collect the ink while moving with the substrate so the ink does not smear, then when the belt separates from the substrate, a separate source of UV light can be used to solidify the ink on the protective layer. Alternatively, the ink may be removed in liquid state from the belt.

The table 712 may be a vacuum table, in which case the material 720 should be sufficiently porous to allow the vacuum to pass through to help hold the substrate 711 in place for printing.

Fig. 7C shows a cross-sectional view of a printing apparatus 705, similar to the apparatus 700 of **Fig. 1**, and through which the web or other substrate 711 of woven or knitted polyester textile material is being fed for printing. The apparatus 705 includes a platen or table 706 over which the web 711 is fed. Printhead carriage 714 is mounted to move across the bridge as illustrated in **Fig. 7A** and has ink jet printhead 715 supported thereon and oriented so as to jet UV curable ink onto the substrate 711 above the table 705. Also mounted on the carriage 714 on opposite sides of the printhead 715 is the pair of UV light curing heads 716 oriented to expose UV ink jetted onto the substrate 711 immediately after the ink reaches the substrate.

The table 705 may be made of metal, for example stainless steel, and has an upwardly facing surface that is coated, at least in the area on which the printhead 715 prints, with the layer of release material 702 thereon. Instead of providing the release material layer 704 with enough adhesion to the ink to prevent it from wiping off by the passage of the substrate 711 over the table 706, the substrate 711 is maintained out of contact with the layer 704 and table 705 in the region between the printhead 715 and the table 706.

Spacing between the table 706 and the substrate 711 is maintained by guide structure such as side securements, support wires or mesh, sets of transverse rollers, or other structure that so maintains the substrate 11 for printing. The guide structure may include sets of transversely extending elements to pinch the fabric and stretch it parallel to and spaced from the table 706. The pinch element sets may each include a pair of smooth low friction bars, a bar and roller set, or a pair of rollers. The pinch elements may, for example, hold the substrate in sufficient tension to keep it in position relative to the printhead for printing and to keep it out of contact with the table 706. In the embodiment of **Fig. 7C**, the guide structure maintains the substrate 711 in tension and spaced above the table 706 a short distance, for example 1/4 inch, so that the material does not touch the surface of the table 706. The tension in the substrate 711 may, for example as shown in **Fig. 7C**, be maintained by two spaced sets 731 and 732 of rolls 731a,731b and 732a,732b, one set 731 upstream of the printhead 715 and one set 732 downstream of the printhead 715, such that the sets are horizontally spaced about three or four inches apart.

The UV curing heads 16 preferably have light sources that focus over a sufficiently long depth of field so as to expose and cure not only ink that deposits on the substrate 711 but that which passes through pores or holes in the weave of the substrate 711 and collects on the underlying release material layer 704 on the table 706 spaced below the substrate 711. As a result, the ink on the release material 704 is sufficiently set or cured so as to be in a powder or otherwise substantially solid state as it enters the cleaning station, so that it can be wiped or otherwise easily removed from the surface of the release material 704.

With the embodiment 705 of **Fig. 7C**, the platen 706 is periodically wiped of the ink that passes through the porous substrate 711 onto the release layer 704.

The above description is representative of certain embodiments of the invention. Those skilled in the art will appreciate that various changes and additions which may be made to the embodiments described above without departing from the principles of the present invention.